UNSTEADY LOADS DUE TO

PROPULSIVE LIFT CONFIGURATIONS

Seventh Quarterly Progress Report
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P. O. Box 8757
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Baltimore, Maryland 21240

Submitted by:

Jeffrey B. Morton
John K. Haviland
George D. Catalano
William W. Herling

Department of Engineering Science and Systems
RESEARCH LABORATORIES FOR THE ENGINEERING SCIENCES
SCHOOL OF ENGINEERING AND APPLIED SCIENCE
UNIVERSITY OF VIRGINIA
CHARLOTTESVILLE, VIRGINIA

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SUMMARY

During the seventh quarter reporting period, July 1 to September 30, 1975, active work continued on three items. The study of the flow of a jet over an airfoil representative of upper surface blowing using laser techniques was continued. Work on the development of experimental techniques for the investigation of unsteady pressures behind a cold model jet was completed, and is presently being incorporated into a Master's thesis[1]. Construction of a 1/4 scale model of the 'Beach' test configuration at Langley was completed with the exception of the inner core jet, and single point measurements were made behind the outer rectangular jet, with and without the wing section installed. Also, construction of a portable detector was completed. This will be used in conjunction with a laser to measure jet flows during the tests on the 'Beach' facility at Langley. The detector incorporates both optical and electronic components.

Two abstracts were submitted to the APS meeting to be held at College Park, Maryland in November. These cover the single point laser characteristic of the jet and the development of probes for unsteady pressures behind cold jets.

INVESTIGATION OF UPPER SURFACE BLOWING FIELD

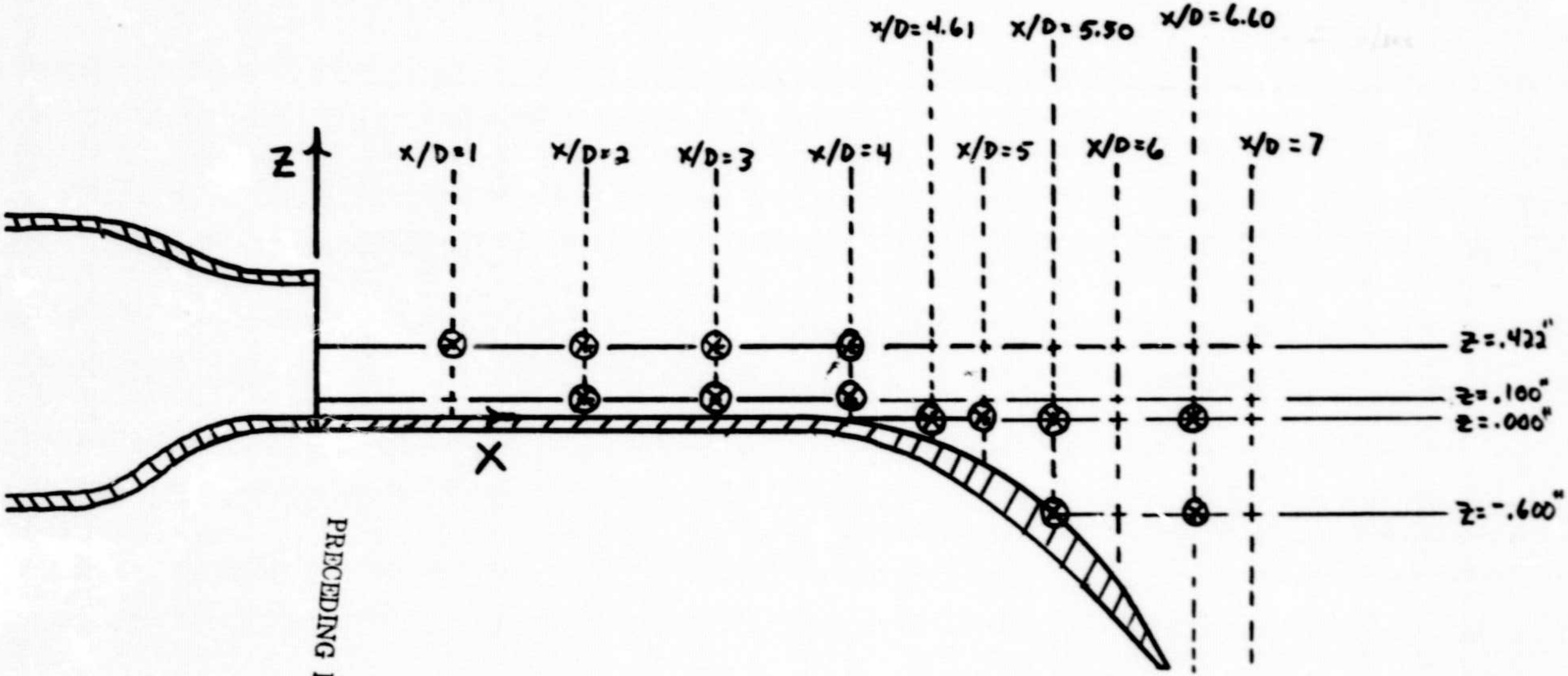
A detailed investigation of the upper surface blowing field is now in progress. The measurements which have been taken by use of a laser Doppler velocimeter include mean velocities, turbulent intensities, autocorrelations of the fluctuating velocity field and power spectral densities. Attention also has been given to determining the extent by which the jet's flow was turned by the flap and to the development of the boundary layer over the wing's surface. Figure 1 indicates the locations of all measurements taken.

Focussing first on the question of the turning of the jet, Figure 2 presents a vectorial diagram of the centerline mean velocities. The concept "mean velocity" has a special significance here in that it corresponds to the maximum mean velocity measured at a given location. The angles that these "maximum" mean velocity vectors make with the horizontal plane are shown in Figure 2. From this information, a qualitative as well as quantitative idea of the efficiency of the flap in turning the flow can be determined.

Turning next to the development of the boundary layer, Figures 3 and 4 present mean velocity ($\bar{U}$) profiles versus height above the surface of the flap for five downstream locations. Notice the actual increase in $\bar{U}_{max}$ at X/D = 4. There quite clearly is a net transfer of kinetic energy from the central region of the jet towards the flap's surface in this region of the flow development.

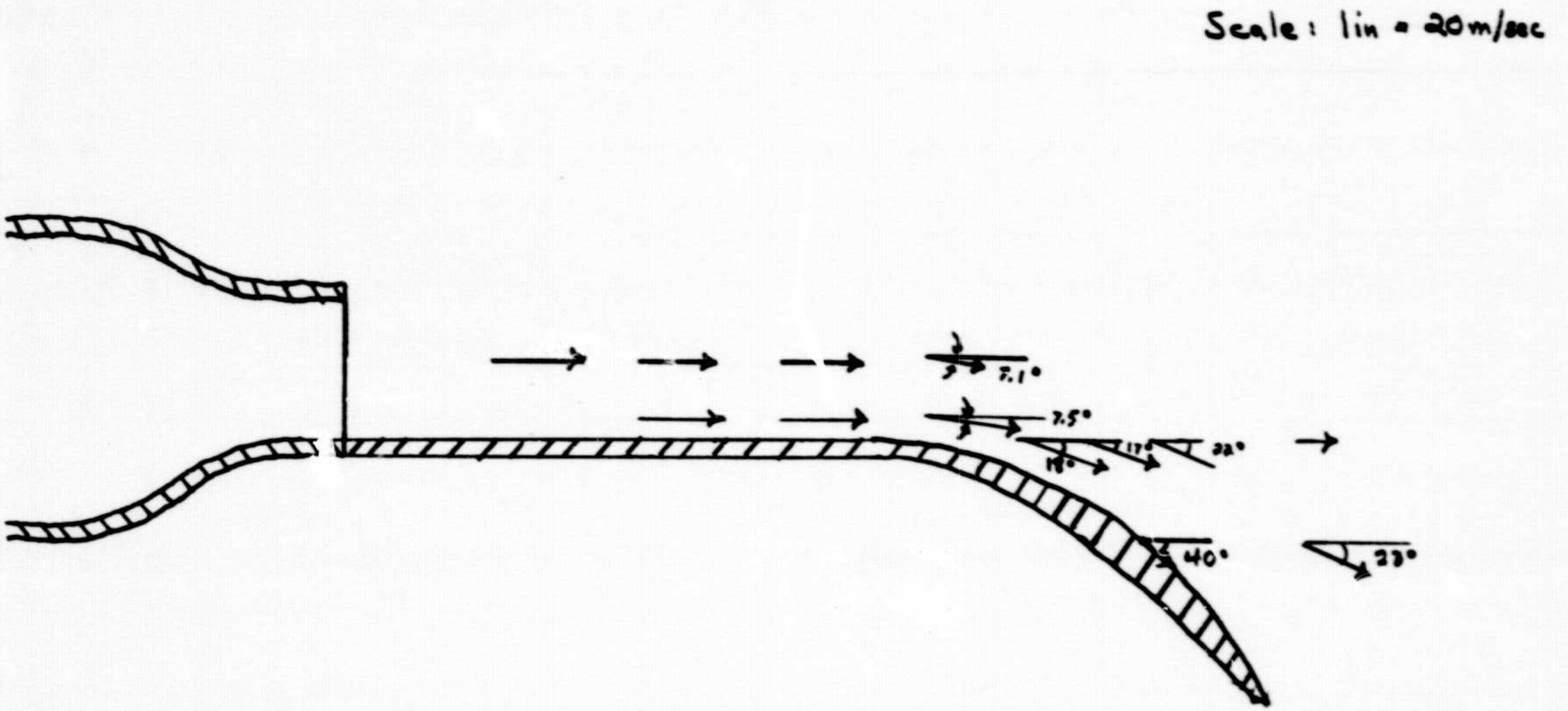
Autocorrelations and their resultant power spectral density plots are presented for the following two locations: (1) Figures 5 and 6 correspond to the location $X/D = 5$, $Y/r_o = 0$, and $Z/r_o = .157$; and (2) Figures 7 and 8 correspond to the location $X/D = 5.5$, $Y/r_o = 0$, $Z/r_o = .078$.

The turbulent intensity profiles presented can be partitioned into two



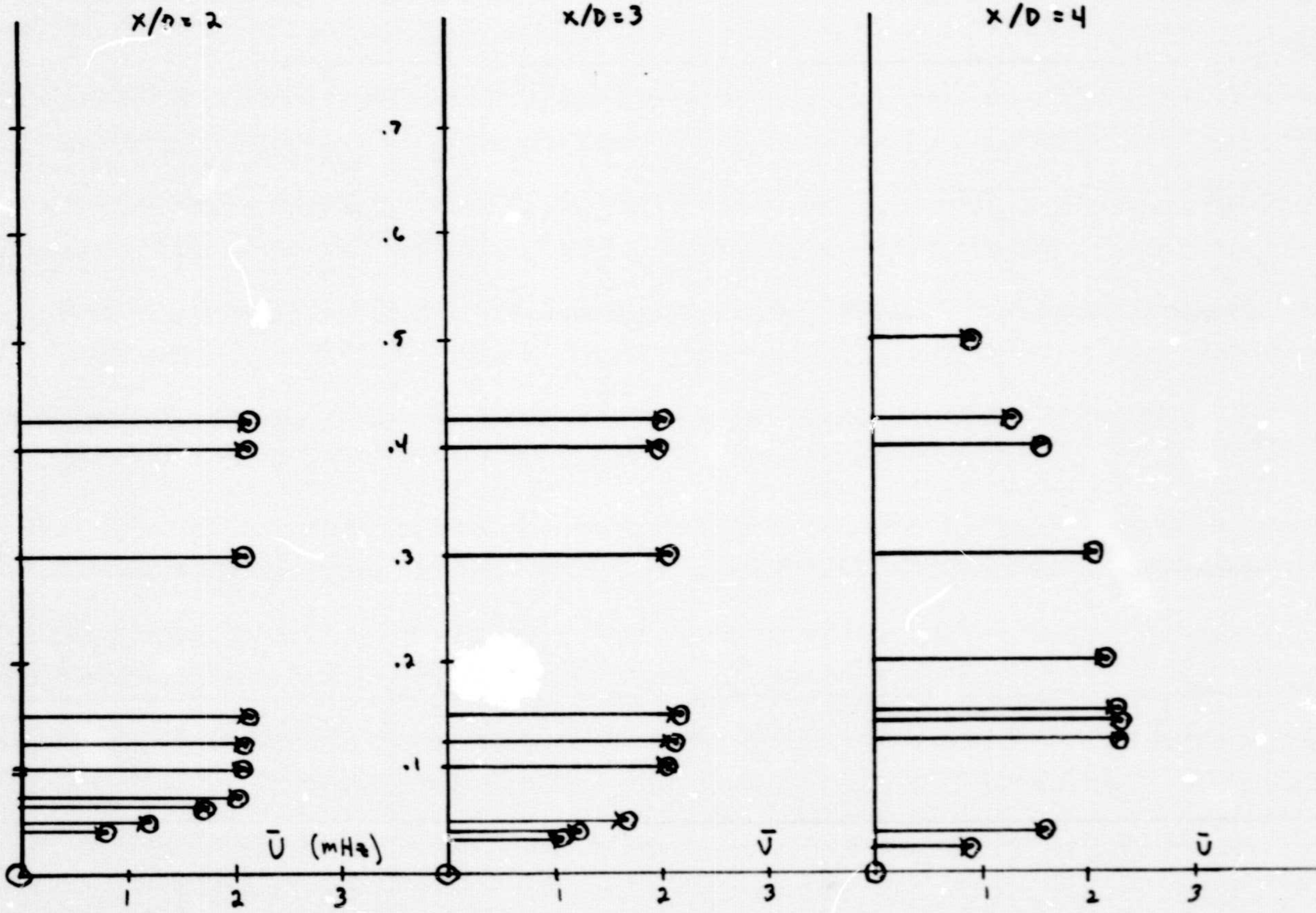
Location of Measurements

Figure 1



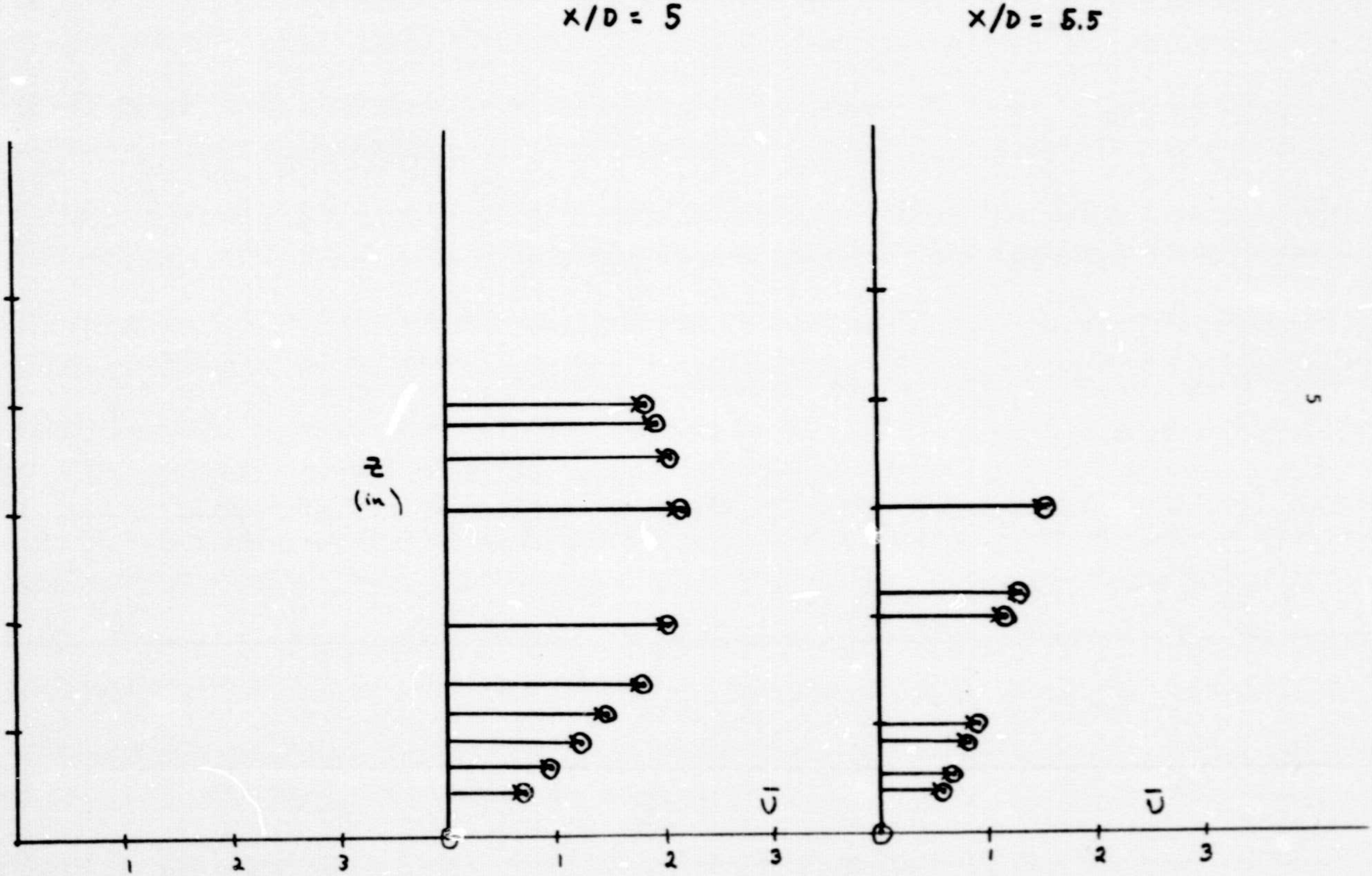
Vectorial Diagram of Centerline Mean Velocities

Figure 2

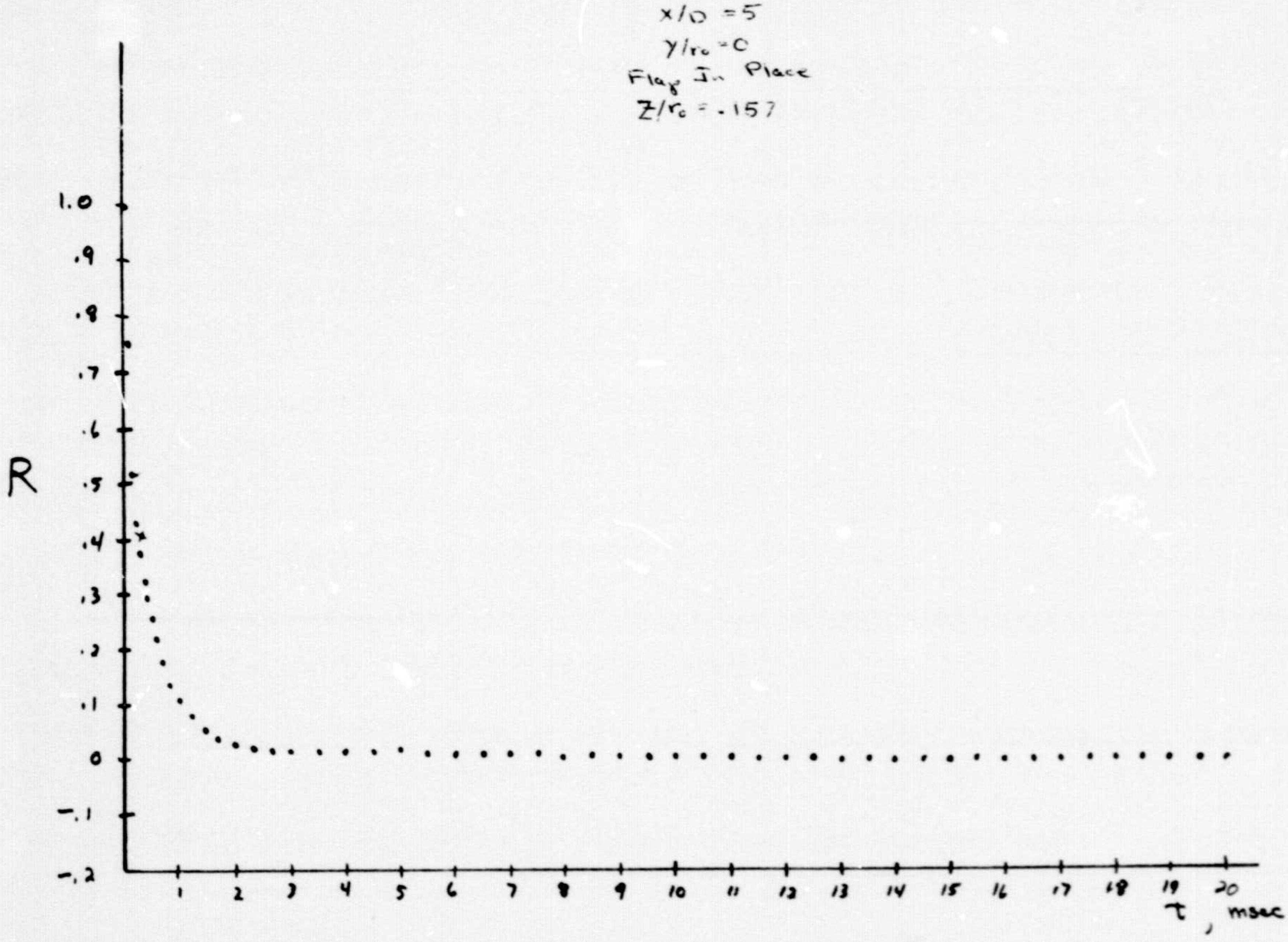


Centerline Boundary Layer Profiles

Figure 3



Centerline Boundary Layer Profiles
Figure 4



Autocorrelation Plots

Figure 5

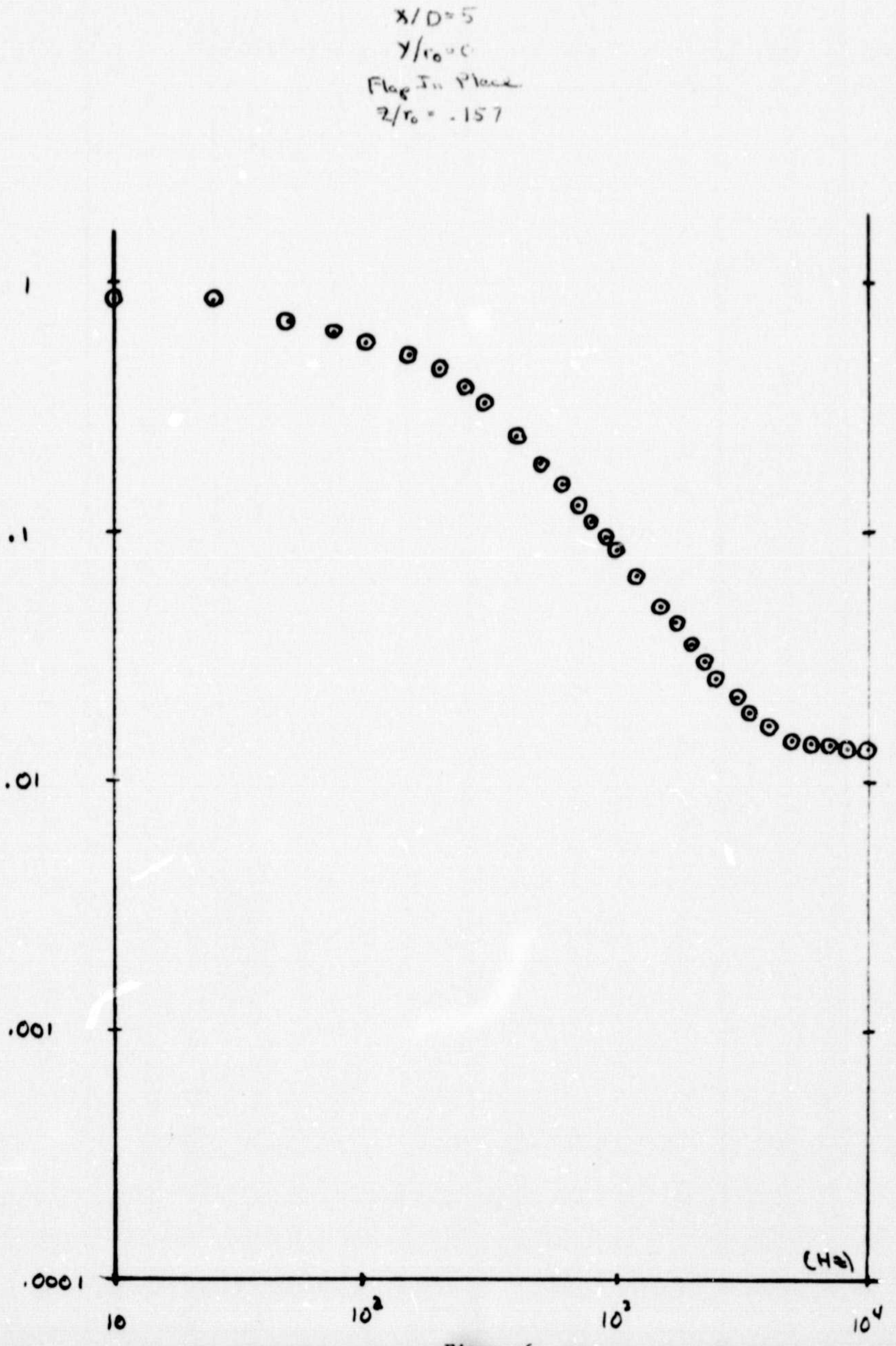
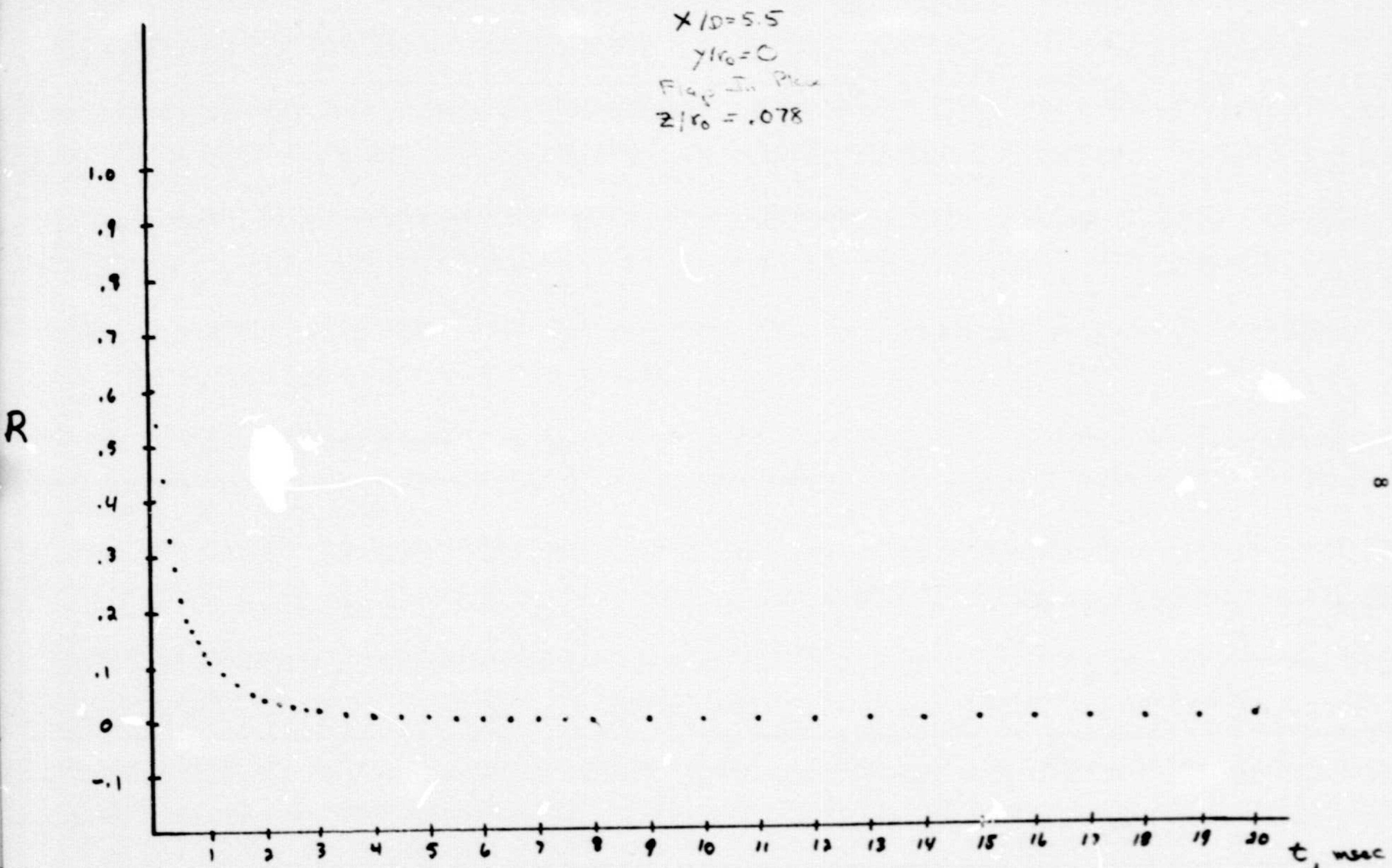


Figure 6



Autocorrelation Plot

Figure 7

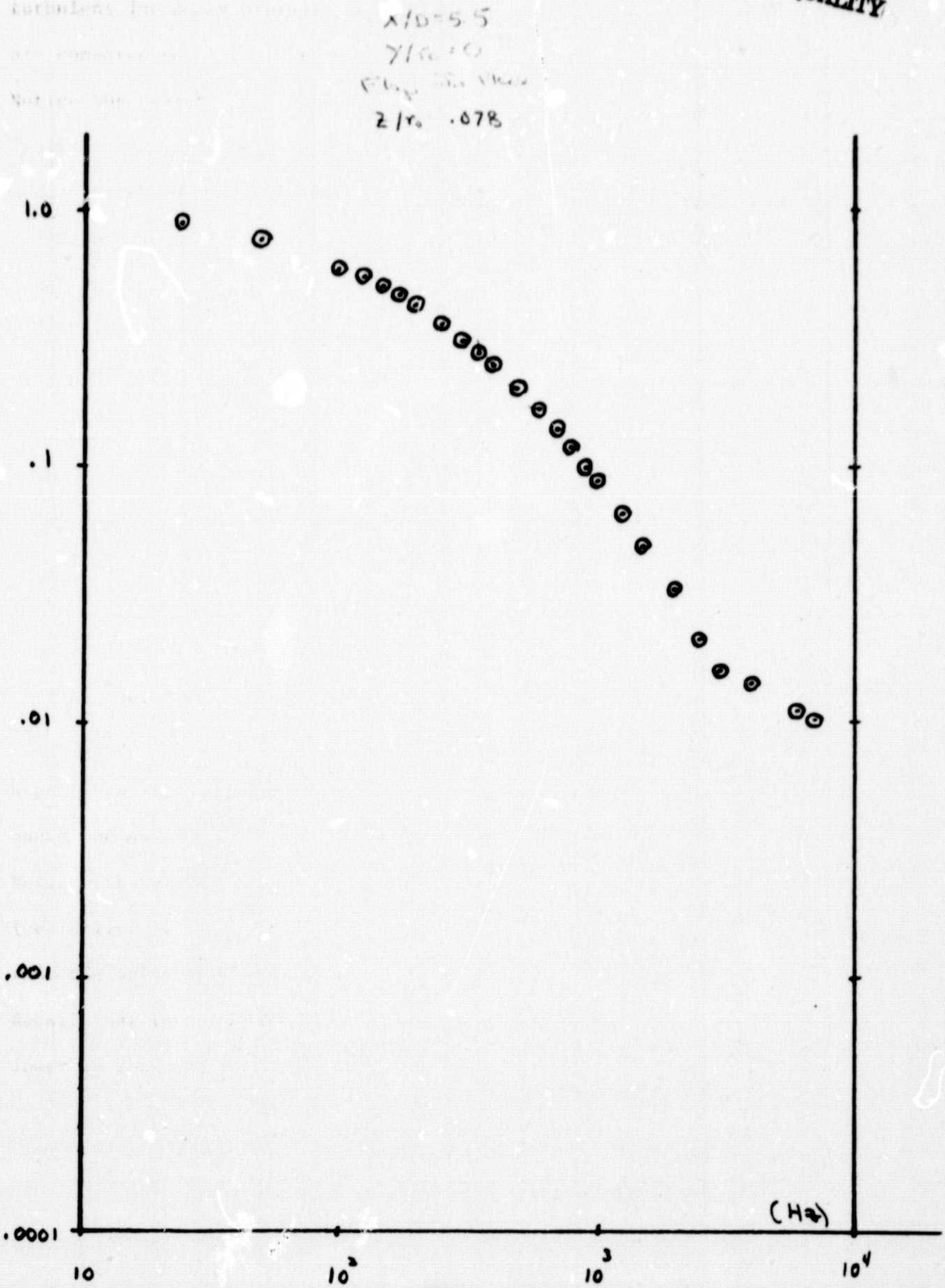
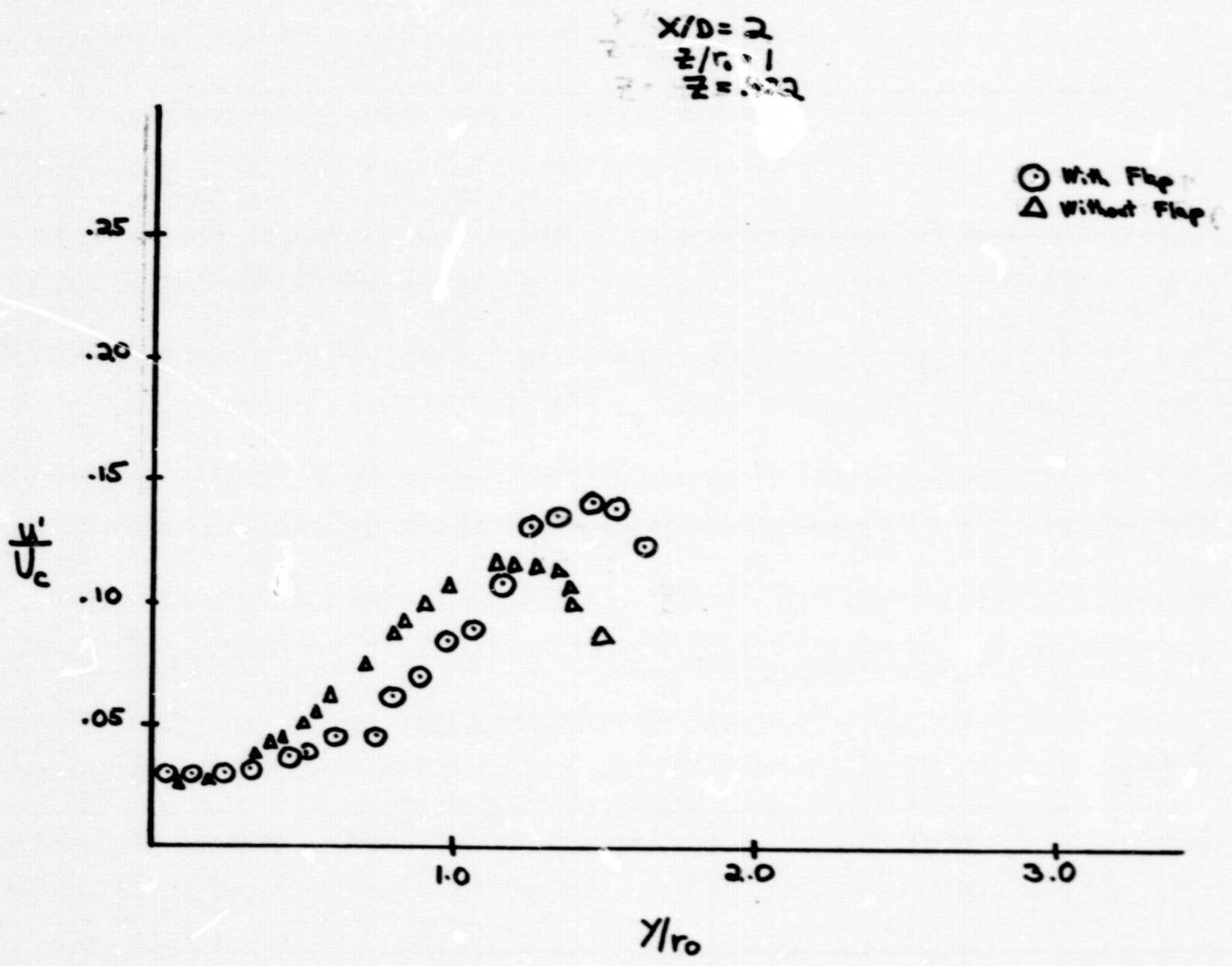


Figure 9

sections. First, for the horizontally flat section of the flap, the turbulent intensity profiles determined at these downstream locations are compared to plots taken without the wing present (Figure 9, 10, 11). Notice the dramatic increase in the turbulent intensity level in the "calm" potential core region of the jet. This occurrence once again demonstrates the profound influence of the flap on the flow field.

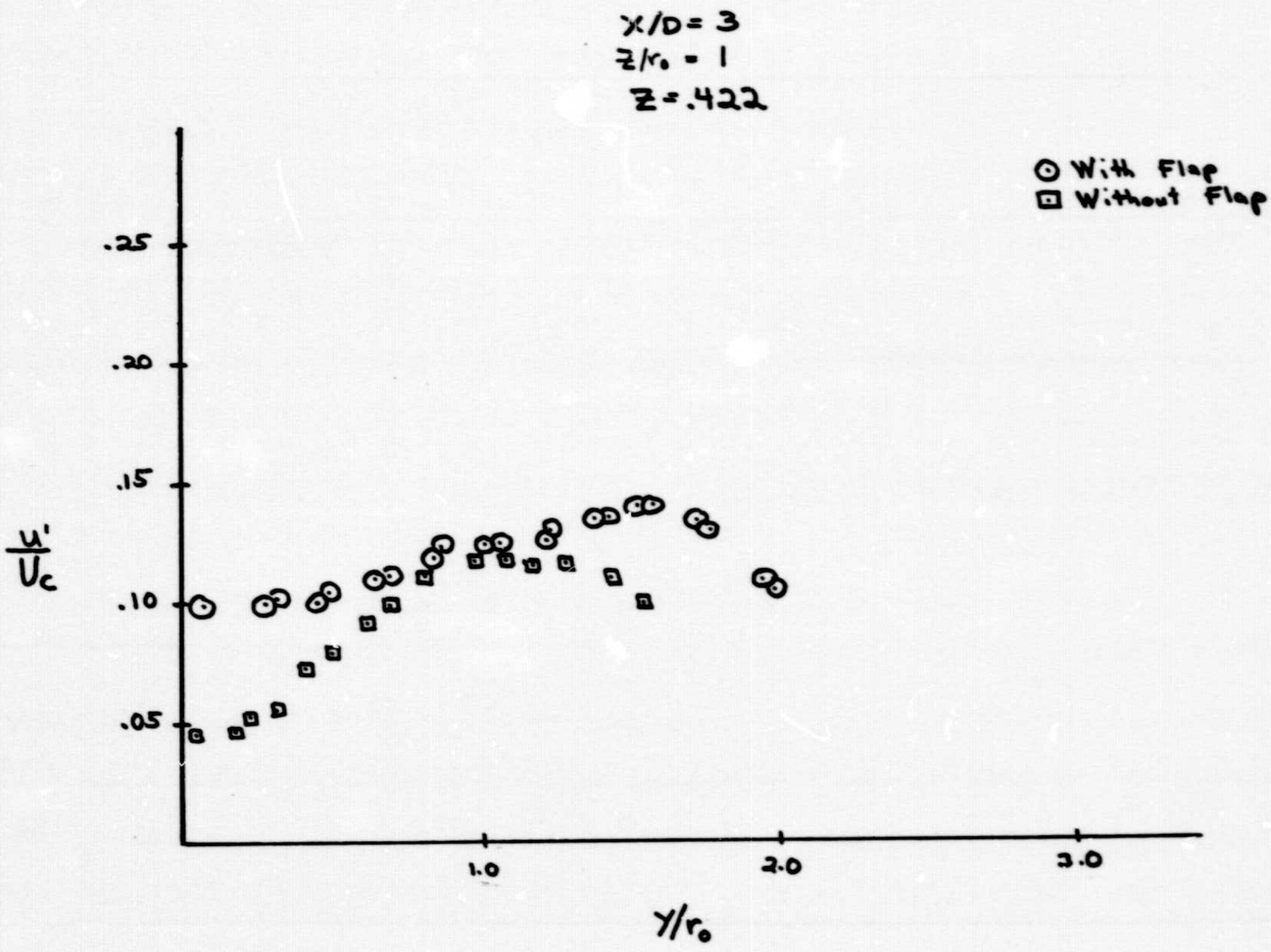
Secondly, the next series of turbulent intensity profiles were taken at various locations in the flow field above the curved section of the flap (Figures 12-15). Two interesting observations can be made concerning Figure 12. Notice the relatively low turbulence level near the centerline of the profile. This would seem to indicate that what is termed the potential core for a free jet has been transported down towards the flap's upper surface. Secondly, the width of this profile is quite notable. These two observations together lend credence to the impression that the axisymmetric jet is being "transformed" into a "quasi-elliptic" shape in cross-section.

Mean velocities in both the X and Z directions have been determined for various locations in the upper surface blowing flow field. Both $\overline{U}$ and $\overline{W}$ profiles are presented at the downstream position $X/D = 4$ for two heights above the surface of the flap (Figure 16-19). Once again notice the contrast between the width of the profiles at $Z/r_o = .370$ and those at $Z/r_o = 1.0$ (centerline of jet). Figure 18 depicts a very interesting $\overline{W}$ profile in that the value of $\overline{W}$ attains a maximum in the outer regions of the flow. Recall that in this part of the flow the turbulence level is still much lower in the center of the profile as compared to the outer edges.



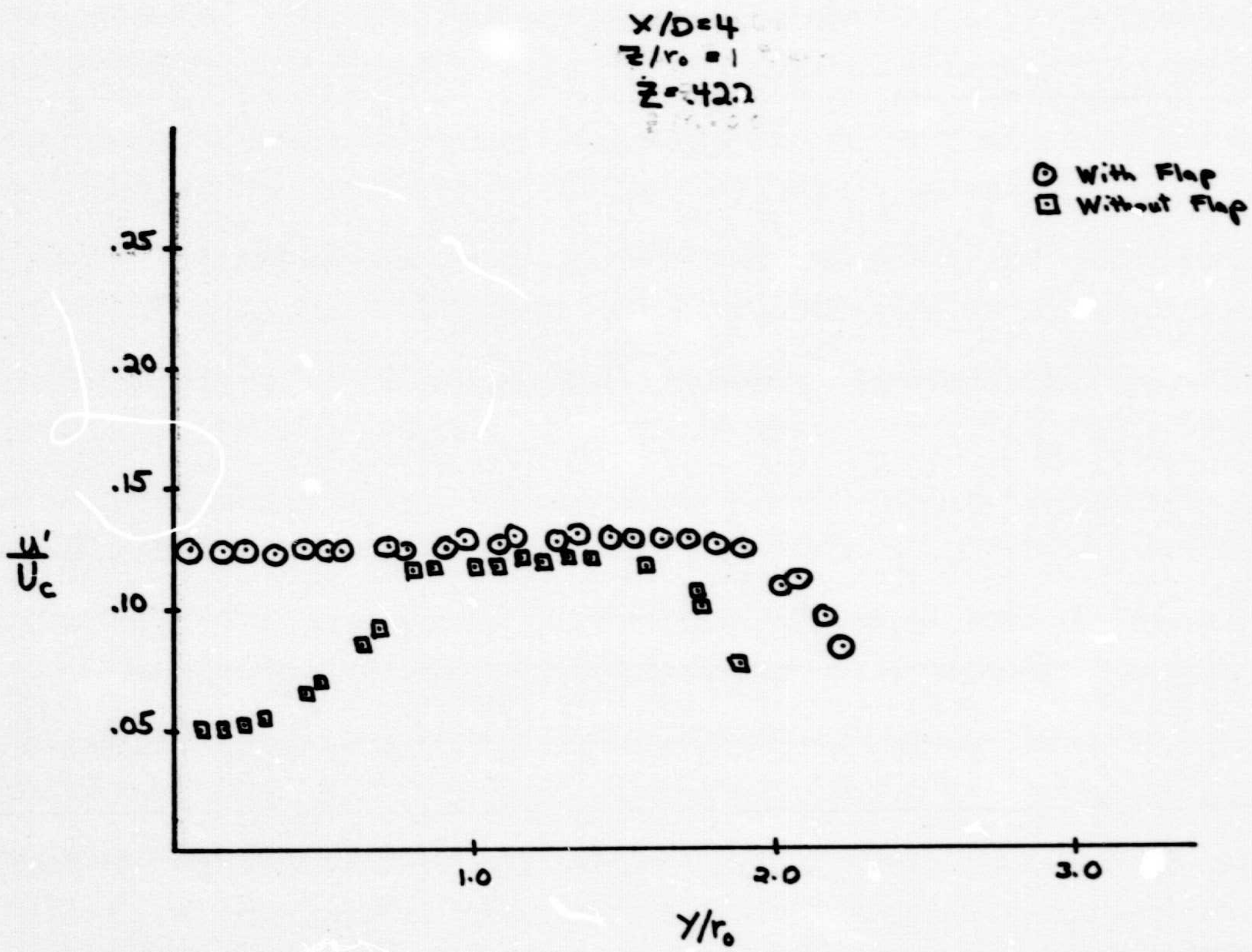
Turbulent Intensity Profile

Figure 9



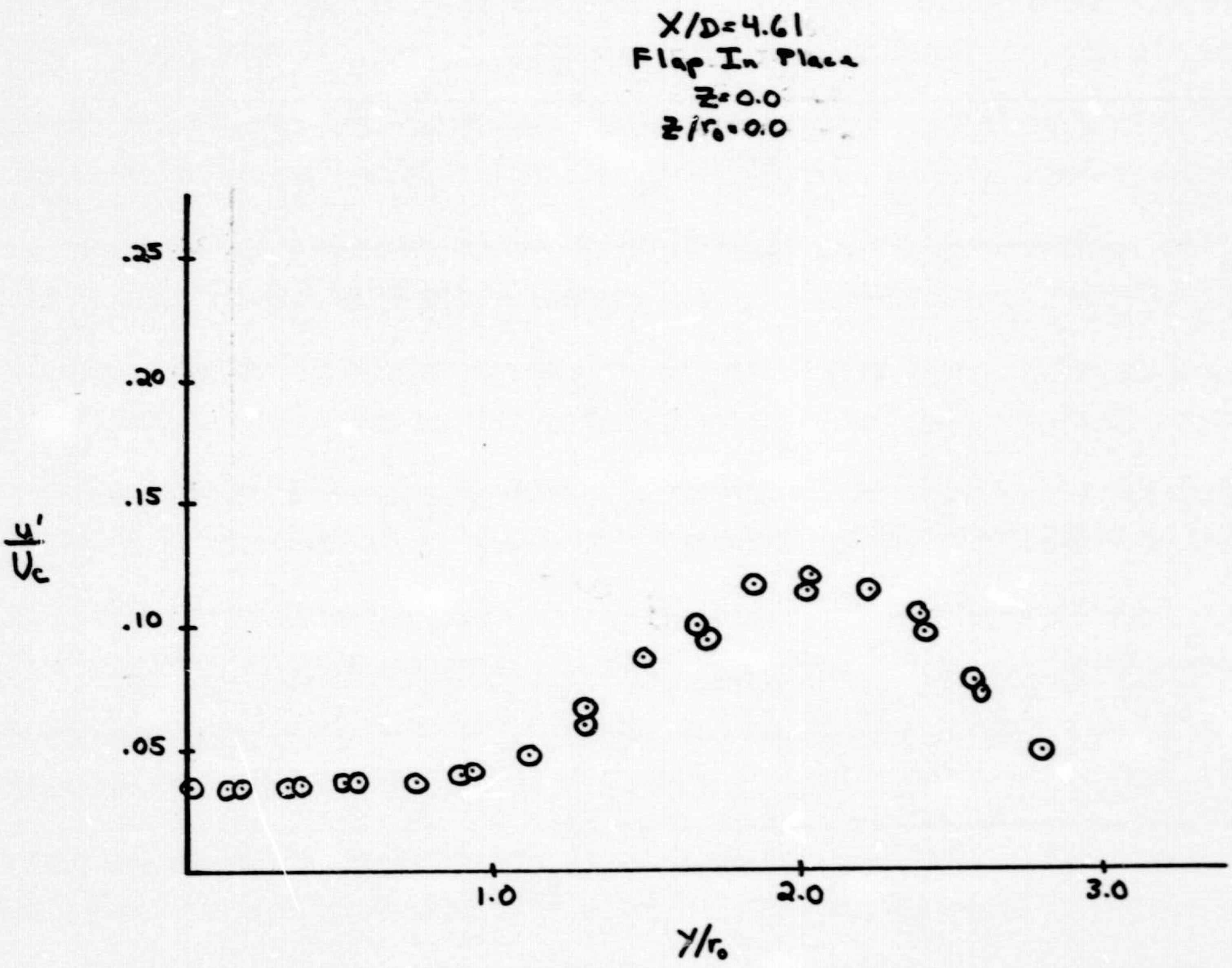
Turbulent Intensity Profile

Figure 10



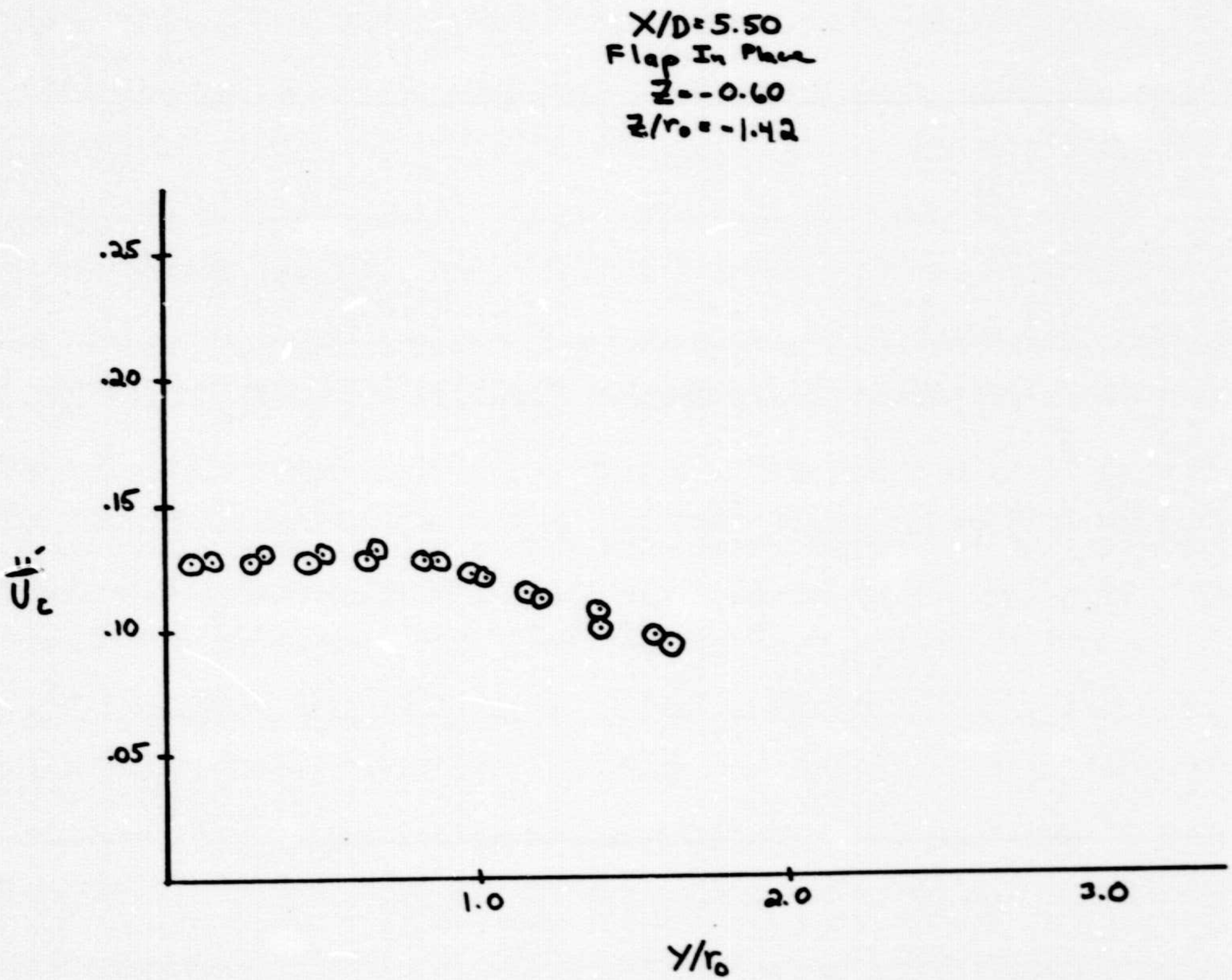
Turbulent Intensity Profile

Figure 11



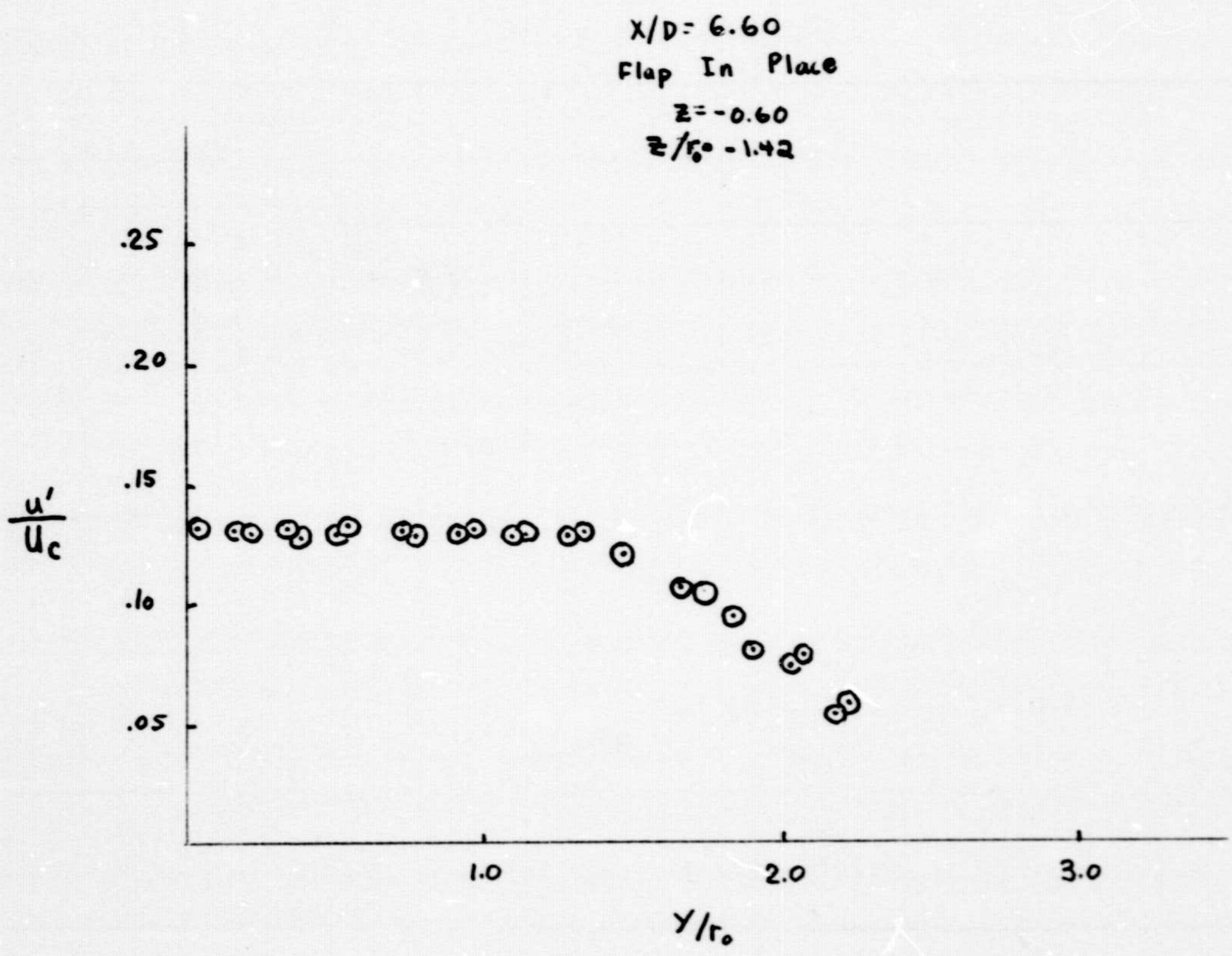
Turbulent Intensity

Figure 12



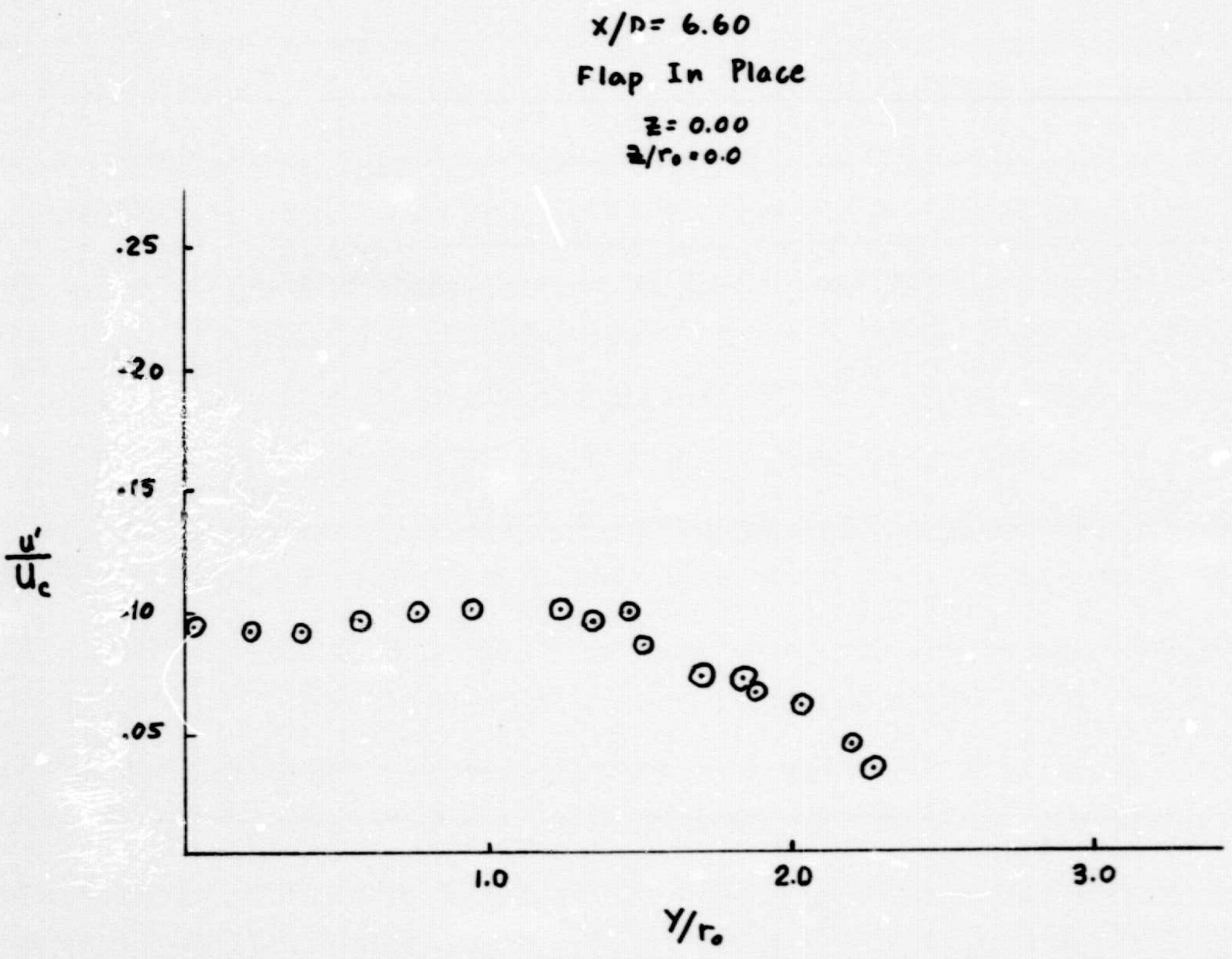
Turbulent Intensity

Figure 13



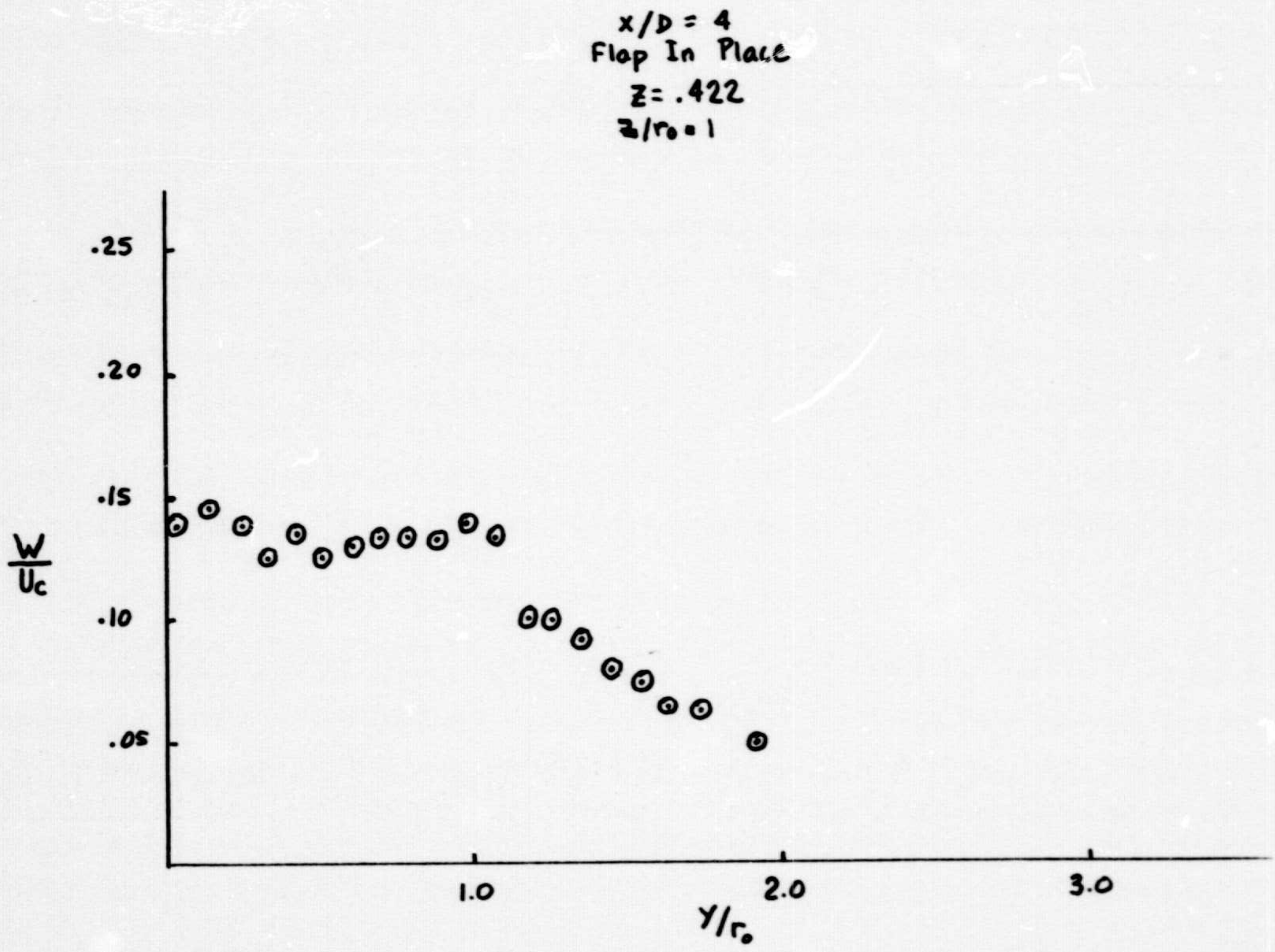
Turbulent Intensity

Figure 14



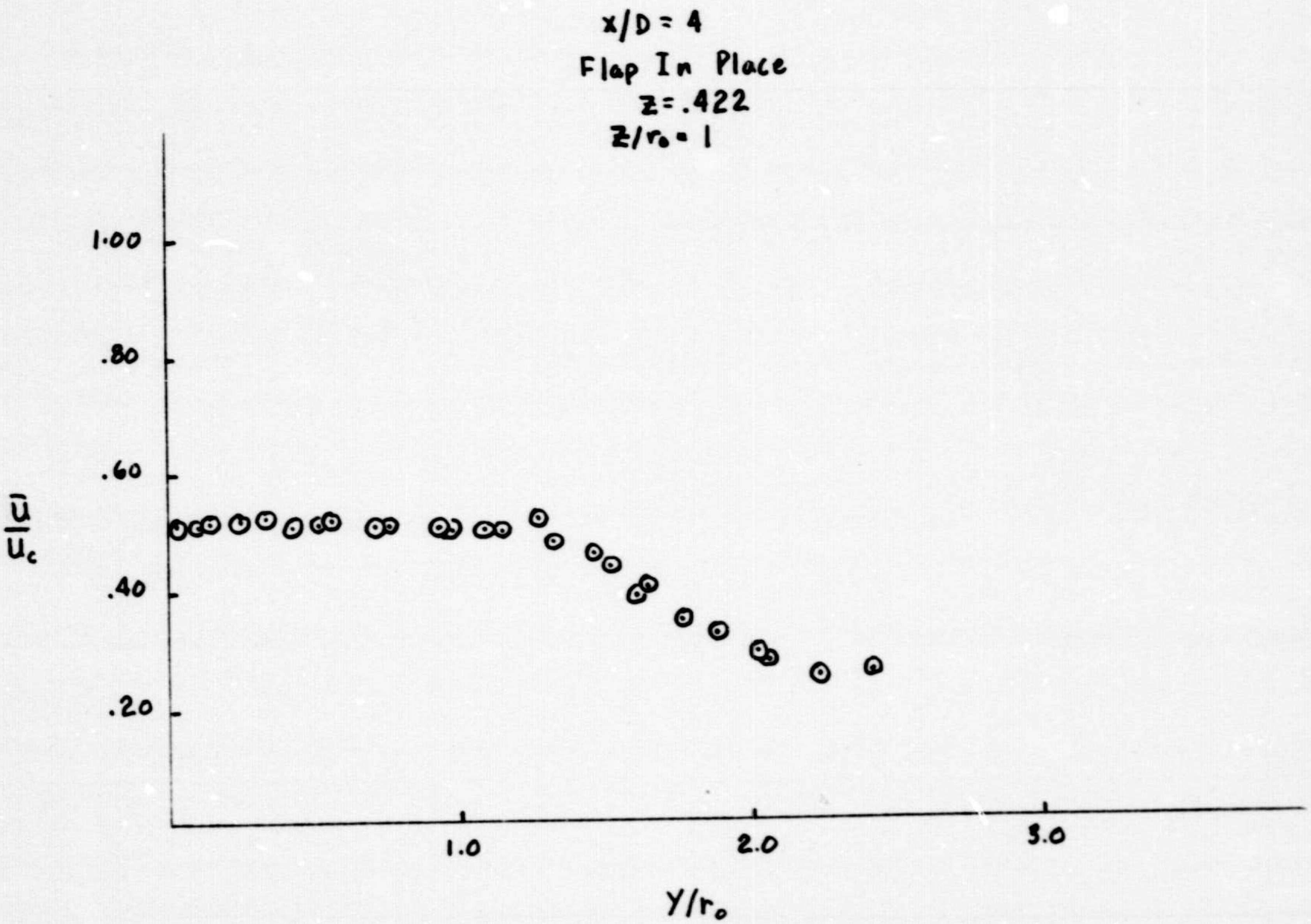
Turbulent Intensity

Figure 15



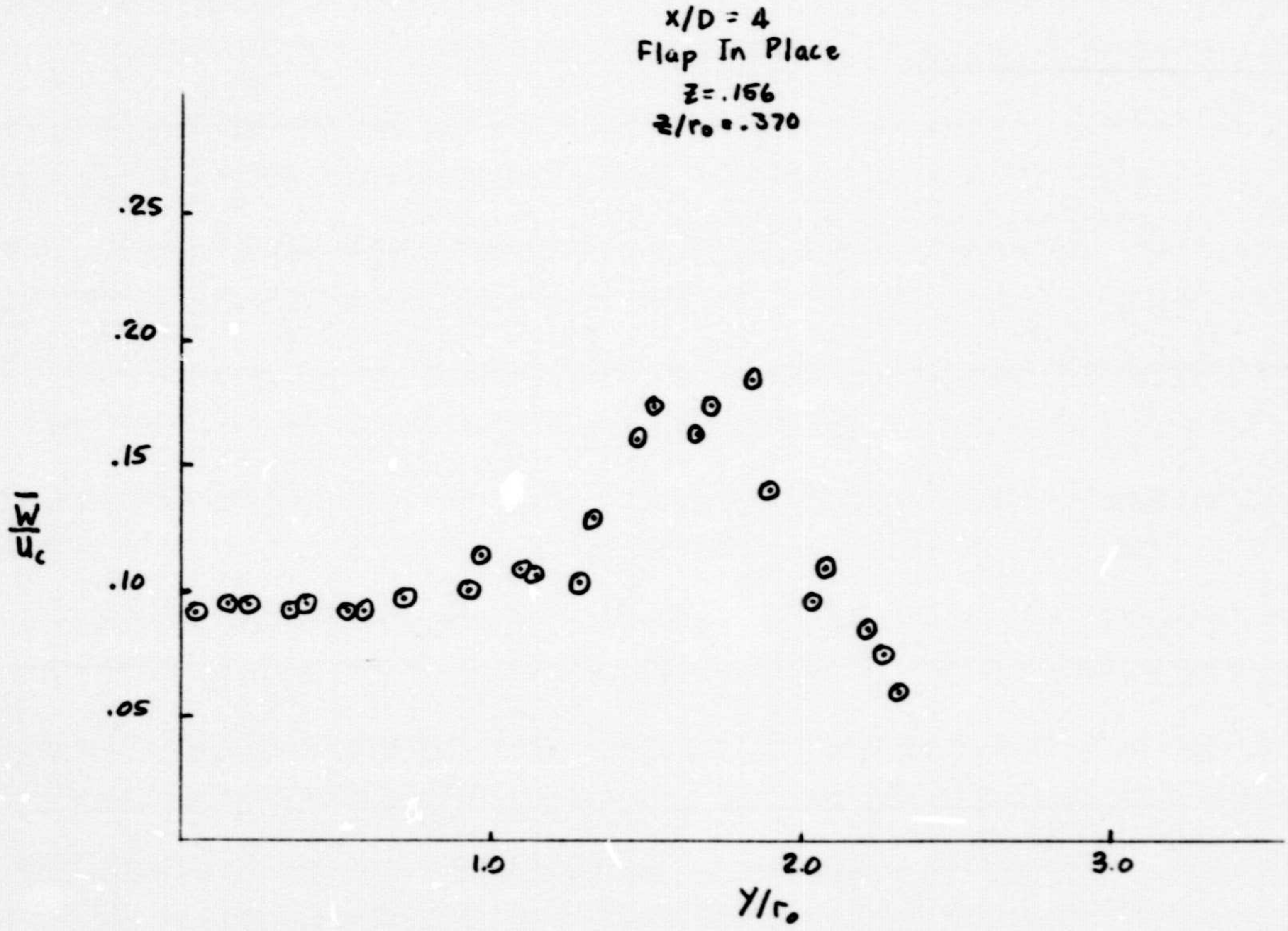
Mean Velocity Profile

Figure 16



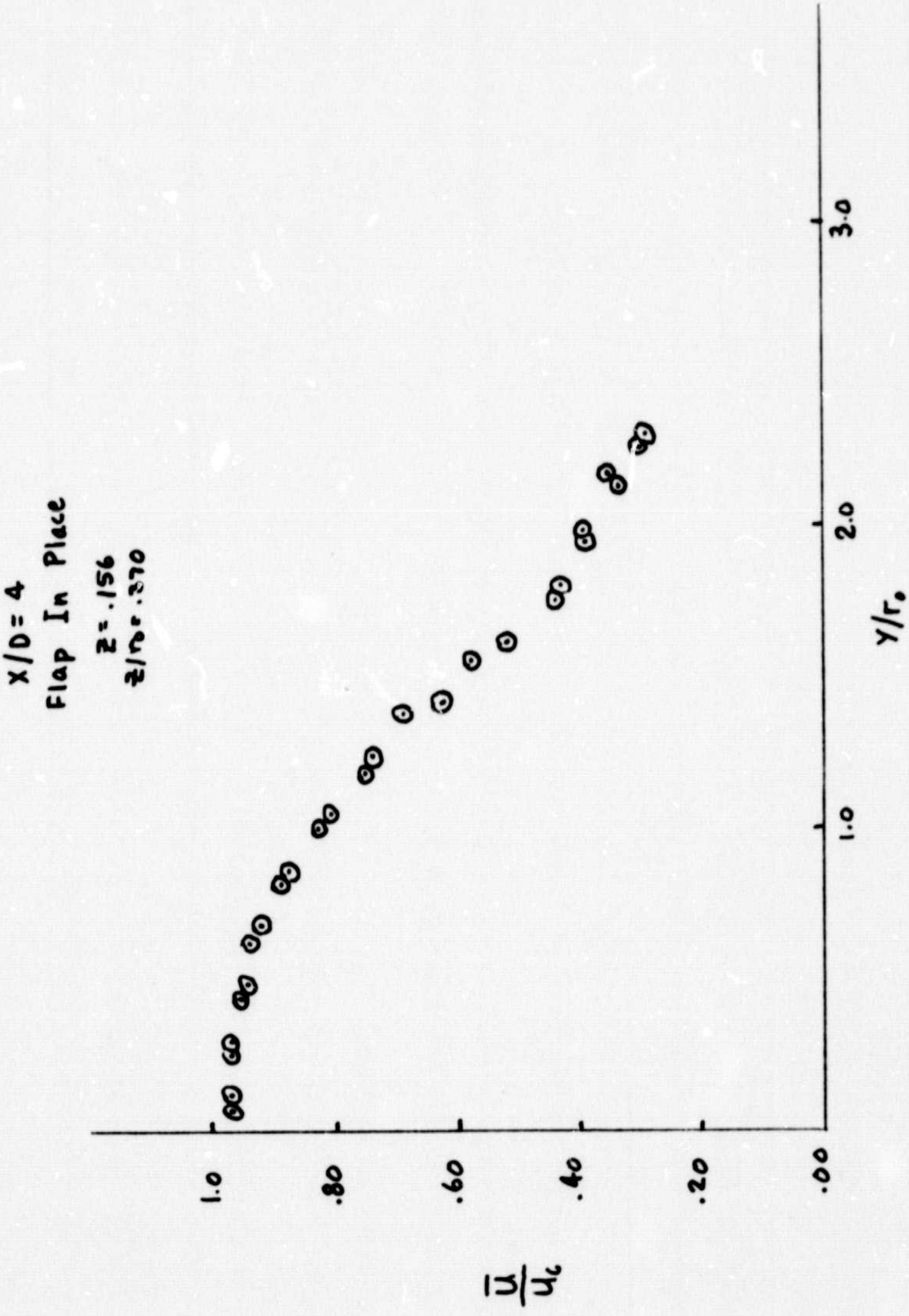
Mean Velocity Profile

Figure 17



Mean Velocity Profile

Figure 18



Mean Velocity Profile

Figure 19

EXPERIMENTAL TECHNIQUES FOR INVESTIGATION OF UNSTEADY PRESSURES BEHIND A COLD MODEL JET

Work on the development of experimental techniques for the measurement of unsteady pressures behind a cold model jet was completed during the period, and is being incorporated into a Master's thesis at this time. It will also be the subject of a report. All of the work was confined to the flow behind a 3.17 cm jet capable of speeds up to 36 m/s., and included both measurements in the free flow, and measurements in the presence of a flat plate which could be inclined at any angle to the flow. The overall effort can be roughly divided into two parts, first, the development of measurement techniques, and second, the application of these techniques to a study of the flow behind the jet, both unobstructed, and with an inclined flat plate inserted. In anticipation of the release of the report, the entire task is summarized below.

Under the development of measuring techniques, three probes were developed. These were miniature pitot (i.e., total pressure) and static probes for the free flow, and miniature orifice probes for surface pressure measurement. Each of these probes was connected to a 1/8 inch B&K microphone by plastic tubing. For evaluation of the static probes, they were located close to a microphone in the region of pseudo-sound, just outside the jet, while the surface probes were located next to flush mounted microphones or to miniature pressure gauges. A digital analysis system was developed both for the analysis of the data taken in the flow during the evaluation of the probes, and for the analysis of the two-point data taken. This consisted of a 512 point digital correlator (Federal Scientific, now Nicolet, Model UC 202-B), modified by the manufacturer to provide output onto a teletype machine. Teletype tapes could then be read into the CDC 6400 computer for further analysis.

The CDC program consisted of a fast Fourier transformation into auto and cross-spectra, for which relative amplitudes, phase angles, and coherences could be obtained. When applied to the evaluation of the probes, the transfer functions of the probes themselves were obtained.

By comparison with theoretical values, analytical expressions for the transfer functions could be obtained which fitted the experimental values. These functions could then be incorporated into the computer program and used to correct the pressure spectra obtained from the probes. It was especially noted that whenever two identical probes were placed close together, their relative amplitudes were close to unity, their relative phases were near zero, and their relative coherences were high. Thus, the probe readings were shown to be dependent entirely on the pressures applied with almost no introduction of noise or other extraneous signals. Conclusions reached concerning the probes, as used in low Mach number flows, could be summarized as follows:

Pitot Probes: Useful for average total pressure measurement in surveying the jet flow. Also useful for measuring convection velocities in unsteady flows. However, the reading of a total head probe in an unsteady flow bears no simple relationship to any definable flow variable although it measures lateral velocity if the total head remains constant.

Static Probe: Useful for measurement of steady or unsteady static pressure in a free flow. However, since it is sensitive to angle of attack, and must therefore be adjusted carefully wherever there is a cross-flow, its accuracy in measuring pressures was considered to be inferior to the accuracies of hot-wire or laser Doppler anemometers used to measure velocities. The static probe is particularly useful for investigating flow relationships between two points.

Surface Probe: Considered to be as accurate as a flush mounted microphone, when properly corrected for transfer function, and more accurate than a miniature pressure transducer, which lacks the sensitivity needed at small jet velocities; there is, of course, no other flow variable of interest which can be measured at a surface, so that no devices, other than those which measure pressure, can be used.

Under the study of the free jet flow, the steady total and static pressures were mapped together with rms values of the unsteady static pressure. Also 1/3 octave spectra of unsteady static pressures were obtained at many places. In a number of cases, two-point analyses were obtained. When one static probe was placed on the jet centerline, and the other was moved out radially, information was obtained which related directly to the structure of the jet flow. The correlation coefficient was found to approach a minimum as the second probe moved behind the jet lip, and then to increase again. This is entirely consistent with the proposed model of the jet flow according to which a series of vortices convect downstream, each one carrying a pressure disturbance with it. Since the vortices become unstable, and develop several lobes, correlation coefficients taken with one probe touching the edges of the vortices are relatively low because of irregularities introduced by the lobes. Further confirmation is given by the near zero relative phase angles and high coherences obtained. When pitot probes are substituted for static probes, very low coherences are obtained. This is because the pitot probes are sensitive mainly to lateral velocities which vary erratically near the lobed vortices. When either type of probe is displaced axially, the slope of the phase angle versus frequency yields the convection velocity of the vortices. Measurements indicate that the vortices are separated by an average distance of

just over two diameters. However, these numbers vary as the vortices move downstream, because they begin to coalesce, and then to break up altogether. Pressure measurements were made on a plate immersed in the jet flow principally to evaluate the surface probes. However, two-point analyses were made at a number of points, from which convection velocities could be established. It was particularly noticeable that the pressure spectra taken on the plates do not show such sharp peaks as do the static probes in the free jet. This could indicate that the structured flow has disappeared, so that the vortices scatter irregularly when they impact the plate, and do not therefore, exhibit such orderly spacing as in the free jet.

PROGRESS ON 1/4 SCALE MODEL OF 'BEACH' TEST FACILITY CONFIGURATION

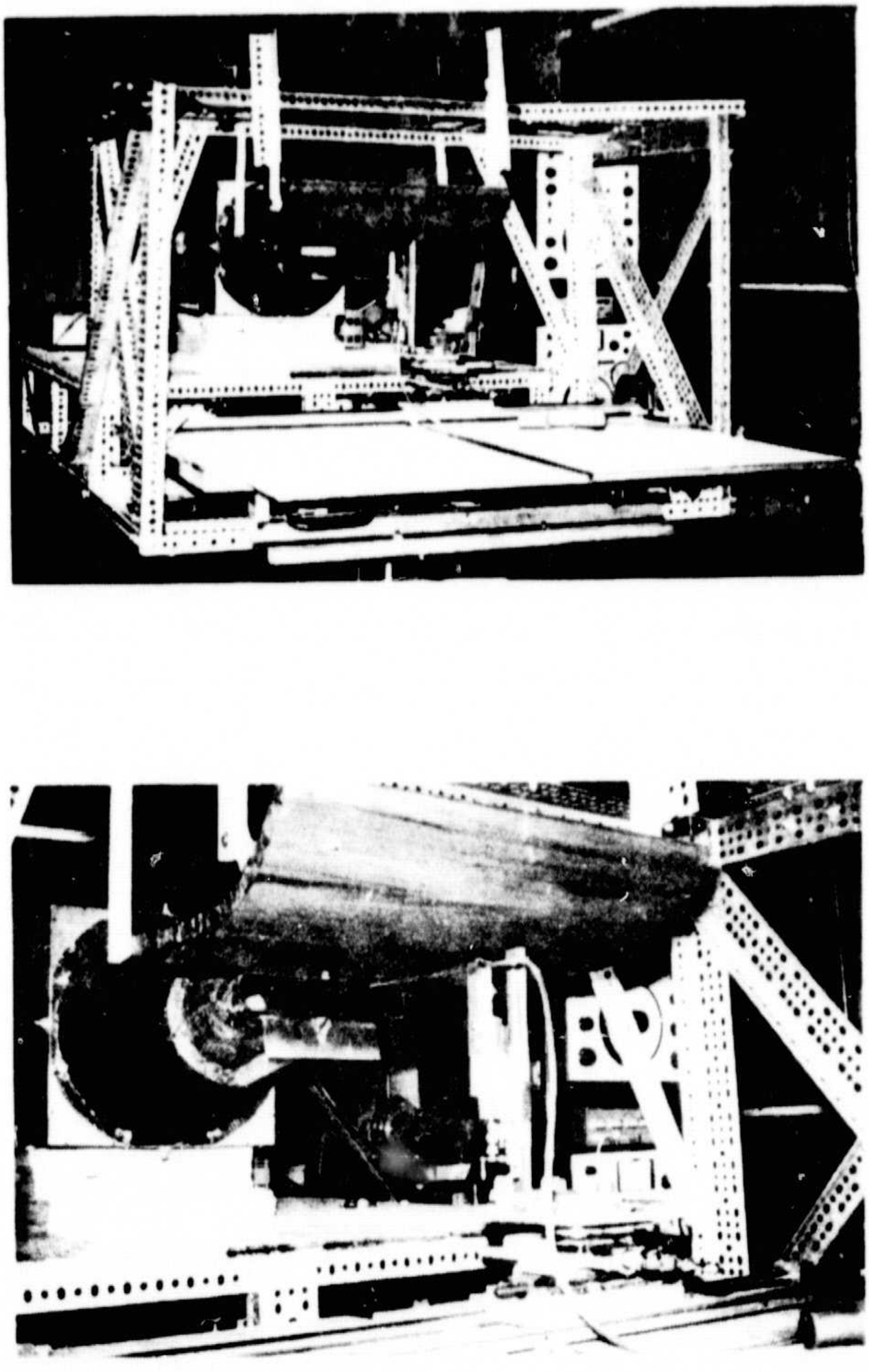
During the period, the 1/4 scale model of the 'beach' test facility configuration was completed, with the exception of the core nozzle. Thus it is now possible to represent the condition of perfect mixing, except for any effects which may be introduced into the jet structure by the internal core nozzle. The facility includes the wing, with removeable flap, constructed from mahogany. The installation of the wing is such that an end plate, representing part of a fuselage, can be added without difficulty. A double probe traverse has been built so that the flow structure in the jet can be studied, both in its free state, and in the presence of the wing. Nozzles are built from fiberglass on a wooden core, which is made by stacking wood cut to section profiles. Any nozzle design can be incorporated by building a new core and laying up the fiberglass. Also, any wing can be added for upper surface blowing, and any flap combination can be added to represent a blown flap configuration.

Surveys of steady state total pressure, and rms unsteady static pressure have been made of the free jet using the probes developed under the program. Also, numerous 1/3 octave spectra have been obtained. There

is evidence in the spectra of a double structure, with characteristic diameters roughly equal to the width and depth of the rectangular jet exit, respectively. In spectra made close to the jet lip, a third component can possibly be traced to the soda straws used to smooth the flow, but this soon dies out as the probe is moved downstream. At present it is only possible to conjecture about the structure of a rectangular jet. We do know that circular jets develop unstable vortices. Presumably, whatever vortices develop in a rectangular jet should break up rapidly, and might exhibit characteristics of smaller vortices, as though they had resulted from a smaller jet. However, it is anticipated that the two-point correlation analyses will permit the structure of this jet to be examined in more detail.

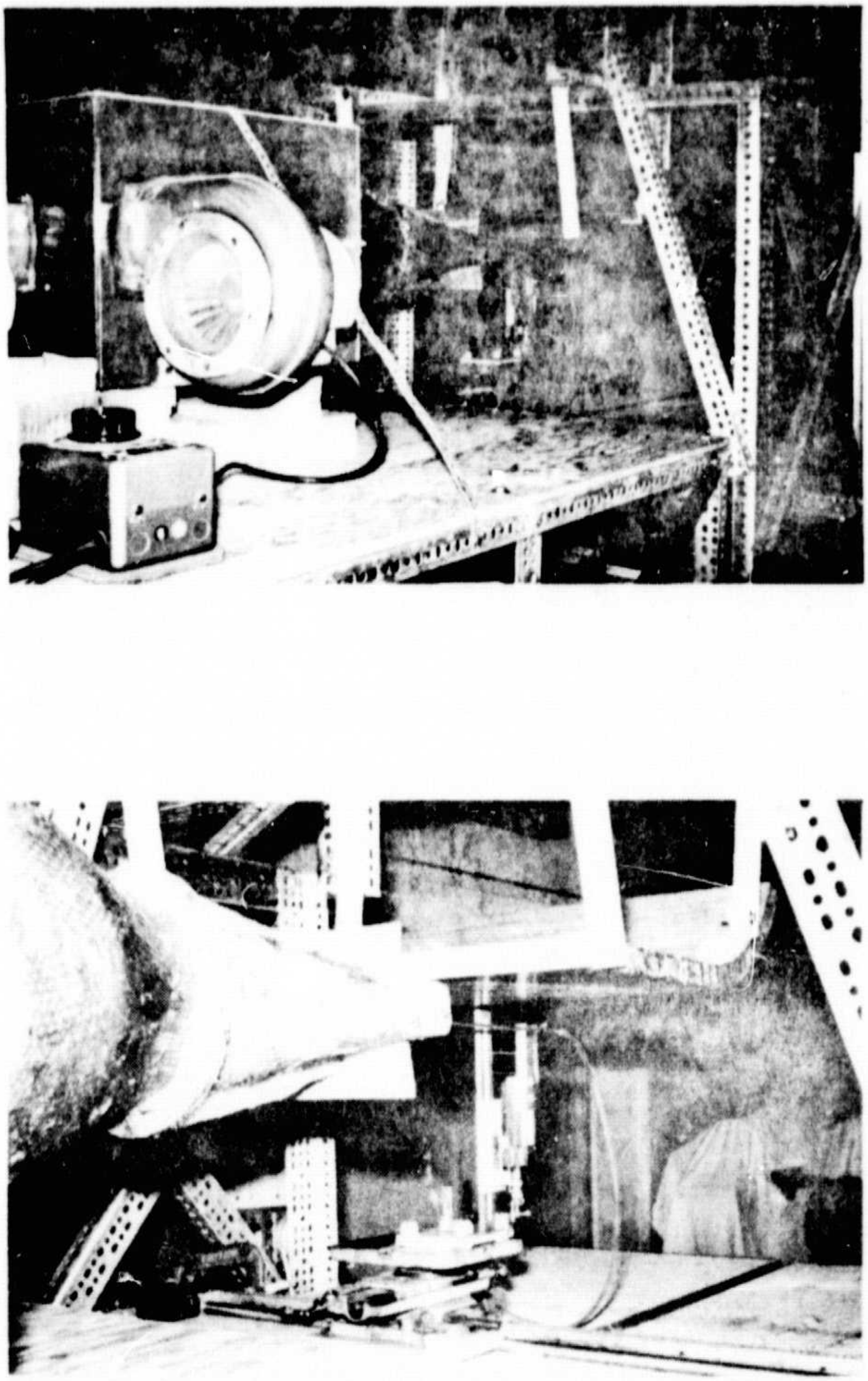
At present, measurements are being made with the wing in place. Indications from the laser experiments have been that the two-point analyses will indicate whether the overall structure is being broken up, or whether the vortices are tending to scatter as they graze the wing surface.

Four photographs of the facility are given as Figures 20 and 21 showing overall and close-up views taken from each end of the facility. The rectangular nozzle, wing, and probes are clearly visible in these photographs. The large box is the plenum chamber, presently supplied from two blowers. Eventually, one of the blowers will supply air to the core nozzle, which will be completely enclosed in the larger rectangular nozzle, so that it would not be visible in these views.



Test Facility Viewed from Downstream

Figure 20



Test Facility Viewed from Upstream

Figure 21

References

1. Schroeder, J. C., "Development of Experimental Techniques for Investigation of Unsteady Pressures Behind a Cold Model Jet," Master's Thesis, The University of Virginia, 1975.